Imaging "Planets" with Laser Guide Star AO

Results of a Keck Laser Guide Star Survey of Young Low Mass objects

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with

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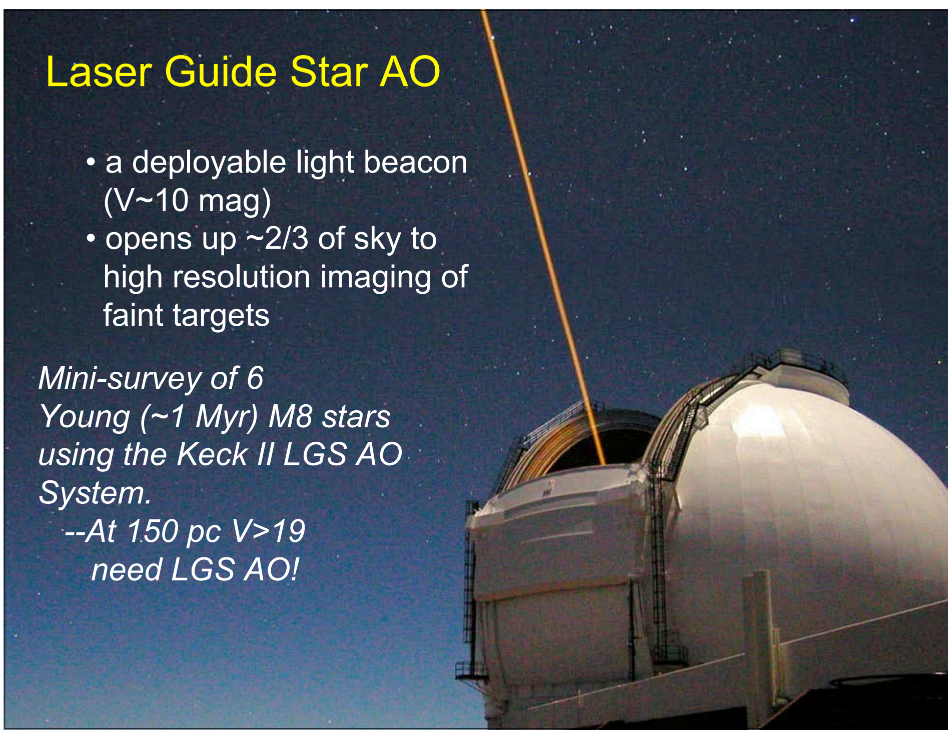
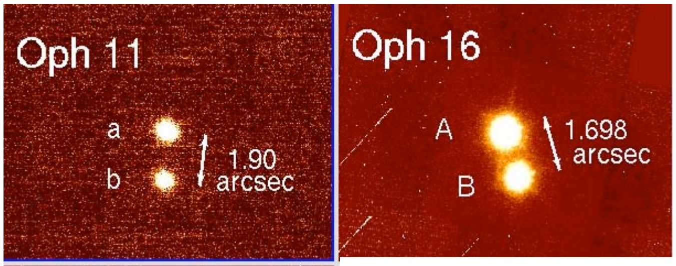
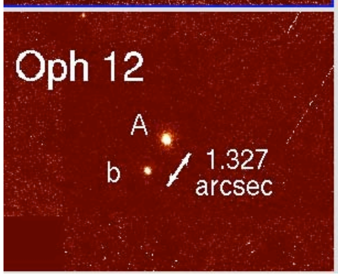
Talk based in part on: The Wide Brown Dwarf Binary Oph1622-2405 and Discovery of A Wide, Low Mass Binary in Ophiuchus (Oph1623-2402): A New Class of Young Evaporating Wide Binaries?
by
Close et al. 2007 ApJ May 20 issue (astroph/0608574)



Young Binary Brown dwarfs in Ophiuchus Imaged with Keck LGS AO & Gemini





- Oph 11AB at a sep~243 AU and with a 17+/-5 Jupiter primary and 14+/-6 Jupiter mass secondary ***is one of the least bound binary known***.
- Oph 16AB has sep=212 AU and 100 and 73 Jupiter masses
- Oph 12 is a chance projection of a z=2 QSO (12b) and G giant (12A).

A Brief History of the Oph 11 Binary Oph1622-2405 : *Six Papers*: SpT_A=M7-M9; SpT_B=M8.75-L0, Age=1-10 Myr; Masses M_A=13-55 & M_B=7-20 Jupiters

- In 2005: Katelyn Allers discovers Oph 11 (for first time) in large Vis/NIR follow-up survey of the Spitzer c2d survey (Evans et al. 2003). Assigns higher masses and T_{effs} (M7 & M8 types) of ages of ~40 Myr in her Ph.D. thesis (also see Allers et al. 2007)
- Spring 2006: Jayawardhana & Ivanov (2006) take spectra of 11AB and find a ~M9 spectral type
- July 2006: Close et al. independently discover Oph 11AB at Gemini and obtain follow-up spectra in August with NIRSPEC.
- August 2006: Jayawardhana & Ivanov publish an on-line Science paper claiming masses of 13-15 and 7-8 Jupiters at 1 Myr. System is labeled as discovery of the first "binary planet".
- August 25: Close et al. find ages of ~5 Myr for the system by comparison to other young standards. Types of M9 and M9.5 and masses of ~17 and 14 Jupiters. Unlikely a binary planet.
- 2006 August: Luhman et al. also submit paper to Ape with similar ~5 Myr ages (part of upper Sco?). But later spectral types (M7.25 & M8.75-M9) and higher masses (above).
- 2006 October: new paper by Jayawardhana's group; Brandeker et al. 2007. Claim ages of 1-10 Myr possible and revise masses upwards (13^{+8}_{-4} and 10^{+5}_{-4}).

A Brief History of the Oph 11 Binary: *Six Papers*: SpT_A=M7-M9; SpT_B=M8.75-L0, Age=1-10 Myr; Masses M_A=13-55 & M_B=7-20 Jupiters

- In 20 | R follow-up
  surv | ses and T_{effs}
  (M7 | et al. 2007)
- Sprir | find a ~M9
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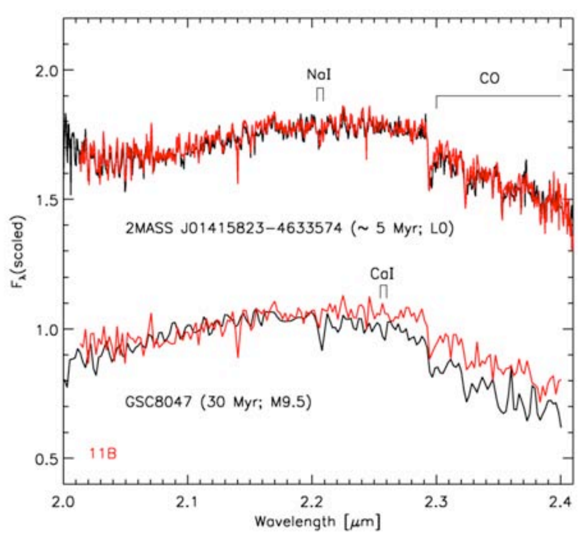
- 2006 | yr ages (part of
  uppe | nasses (above).
- 2006 | 07. Claim ages
  of 1-

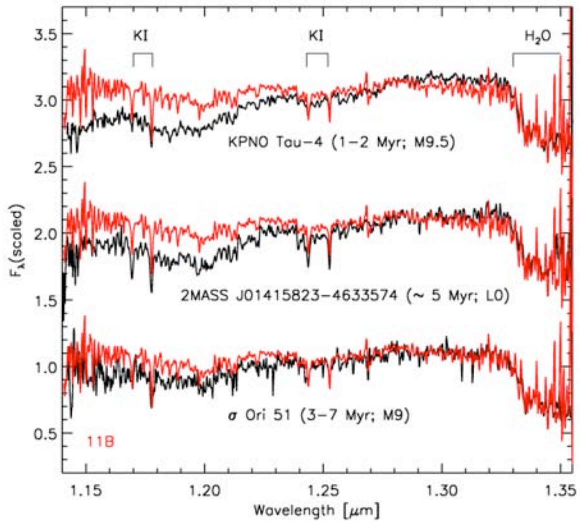
In a nutshell: Oph 11 B was discovered 3 times by three different groups leading to ~6 papers and 6 different masses in each paper!!

Astronomers tend to agree to disagree on the ages/spectral types/masses of young low mass objects…

--- just wait until we start imaging real planets… where the models and templates are even more uncertain…

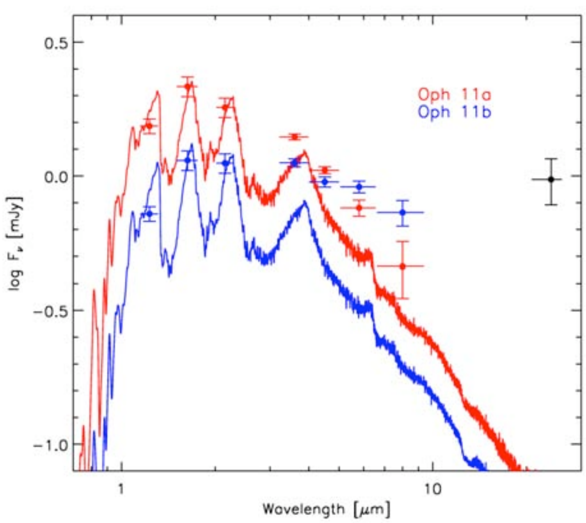
Our R~1900 spectra of Oph 11B in the K band suggests an age of ~5 Myr (as do Luhman et al. 2007) and effective temperatures of 2175+/-175K (M9.5+/-1)



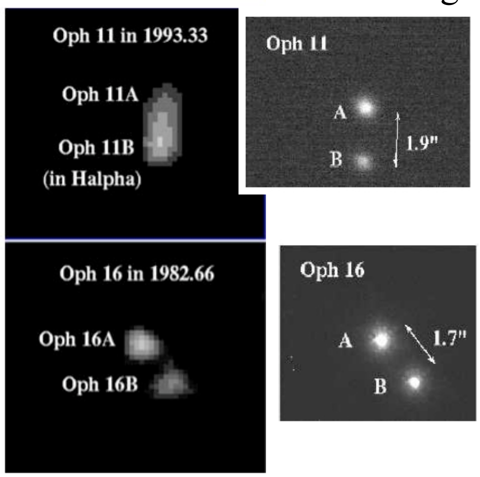


Our J band spectra also suggests 5 Myr with a slightly hotter ~M9 spectral type. There is a poor fit to the gravity sensitive features of 1 Myr standards like KPNO Tau-4

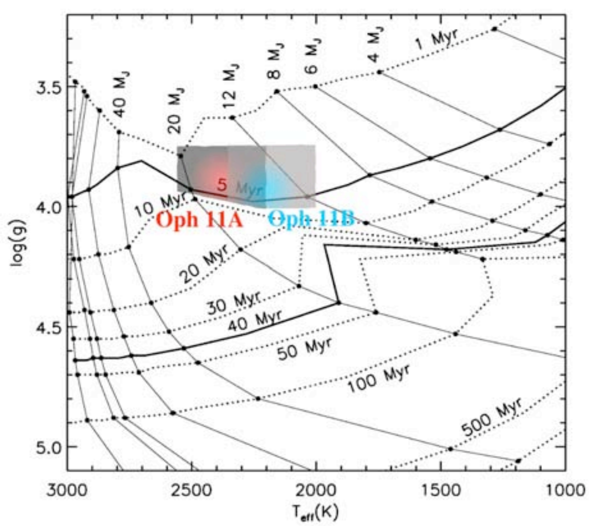
Oph 11A and 11B are both young with IR excess SEDs



Oph 11A and 11B are both likely common proper motion and not a foreground pair

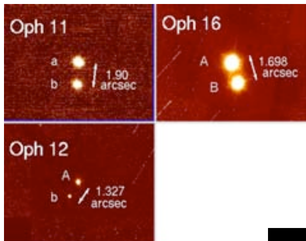


By processing old DSS images we can see that the orbital motion of Oph 11 and 16 is consistent with zero w.r.t. each other (<3+/-5 km/s). This is only consistent with bound 10^4 yr orbits



The log(g)/T_{eff} plane of the Chabrier et al. dusty models (and the HR diagram) suggests 17+/-5 and 14+/-6 Jupiter masses as the most consistent fit to the models (which have additional systematic errors).

Young Jupiters of 4 M_{jup} are fairly bright (J~18 D=125 pc) on the HR diagram… See Oph 12b for example



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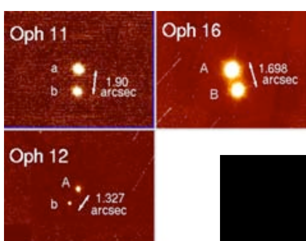
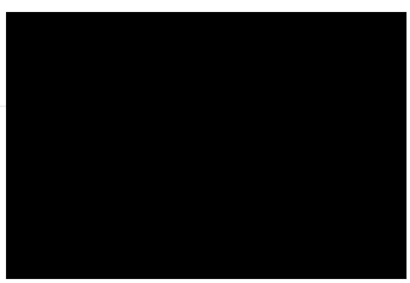
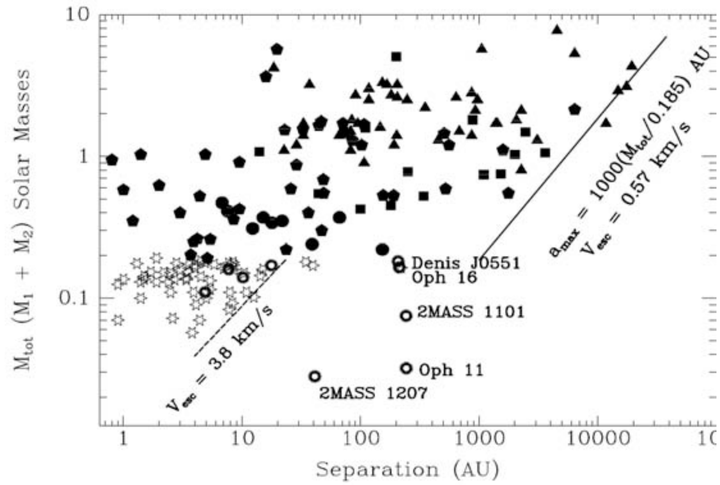




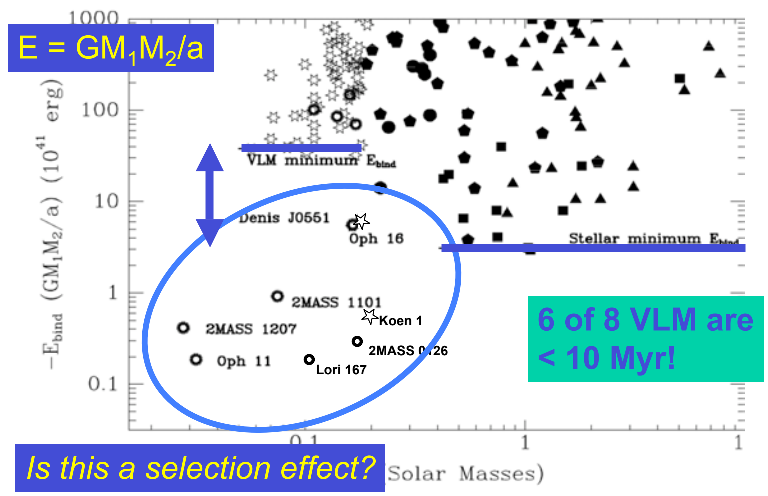
LGS AO is a "low-contrast" approach to imaging planetary mass companions

We are just realizing that young, very low mass, systems can be much wider than what we see in the field



Since VLM systems have q>0.5 – Target a 20 Jupiter (1 Myr) primary for a <10 Jupiter secondary --- LGS AO!

Binding Energies



Why are there effectively no "Oph 11"s detected in the field today?

The Fokker-Planck equations can help us estimate if these binaries can be evaporated by encounters in their clusters and in the field…

To investigate the stability of wide binaries we note that Weinberg et al.(1987)'s analytic solution of Fokker-Planck (FP) coefficients describing advective diffusion of a binary due to stellar encounters is $t_*(a_o) \sim 3.6 \times 10^5 (n_*/0.05pc^{-3})^{-1} * (M_{tot}/M_\odot) * (M_*/M_\odot)^{-2} * (V_{rel}/20kms^{-1})(a_o/AU)^{-1}$Gyr where $t_*(a_o)$ is the time required to evaporate a binary of an initial semi-major axis of a_o, the number density of stellar perturbers is n_* of mass M_* and relative velocity V_{rel} (adopted from Weinberg (1987); assuming, as they do, that their $ln\Lambda \sim 1$). Hence, the *maximum* projected separation of a bound binary (assuming semi-major axis $a = 1.26 \times sep$; Fischer & Marcy 1992) after 10 Gyr in the field is given by:

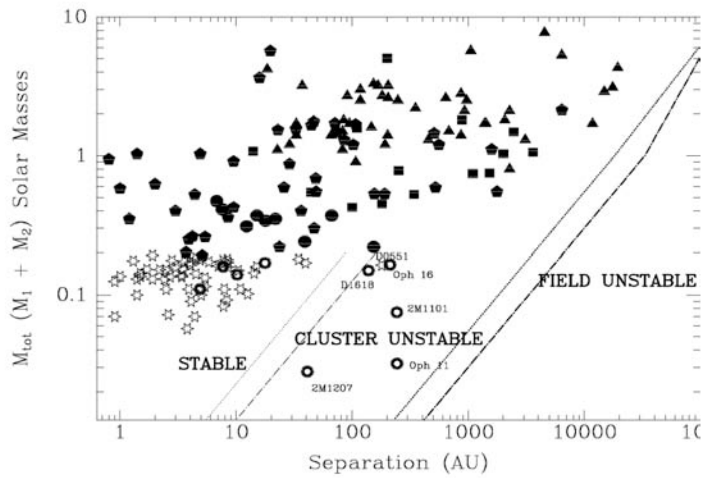
$$sep_{field}^{diffusive*} \lesssim 28 \times 10^3 \left(\frac{0.16}{0.05pc^{-3}}\right)^{-1} \left(\frac{M_{tot}}{M_\odot}\right) \left(\frac{0.7}{M_\odot}\right)^{-2} \sim 1800 \left(\frac{M_{tot}}{0.1M_\odot}\right) AU \quad (1)$$

where we have used the measured Galactic disk mass density of $0.11 M_\odot/pc^{-3}$ and an average perturber mass of $0.7M_\odot$, and $V_{rel} \sim 20$ km/s (Pham et al. 1997; Holmberg & Flynn 2000).

In addition to the evaporation of binaries due to diffusion there is also the chance of a catastrophic encounter evaporating the binary. While such encounters are less important than diffusion, they cannot be completely ignored. From the work of Weinberg et al. we find the *maximum* projected separation (*sep*) of a binary to stay bound w.r.t. close encounters over 10 Gyr in the field is:

$$sep_{field}^{catastrophic*} \lesssim 52 \times 10^3 \left(\frac{0.16}{0.05pc^{-3}}\right)^{-1} \left(\frac{M_{tot}}{M_\odot}\right) \left(\frac{0.7}{M_\odot}\right)^{-2} \sim 3300 \left(\frac{M_{tot}}{0.1M_\odot}\right) AU \quad (2)$$

We can estimate "instability" zones the Fokker-Planck solutions of Weinberg et al. (1987) applied to different stellar densities: This approach explains most of the features we observe…



In Close et al (2007) there is the first derivation of "zones" of stability w.r.t. the mass and separation and formation cluster density of binary brown dwarfs. They show that most known wide binary brown dwarfs are young (open circles) and will likely be dissolved in their natal clusters before they join the field (old) population (open stars).

CAN WE SEE ROCKY PLANETS WITH AO?

---- WELL NO NOT USUALLY (not even close)

BUT SOMETIMES EVEN ROCKY PLANETS CAN BE SELF-LUMINOUS…

FOR EXAMPLE WHEN OUR MOON FORMED…

CAN WE SEE ROCKY PLANETS WITH LGS?

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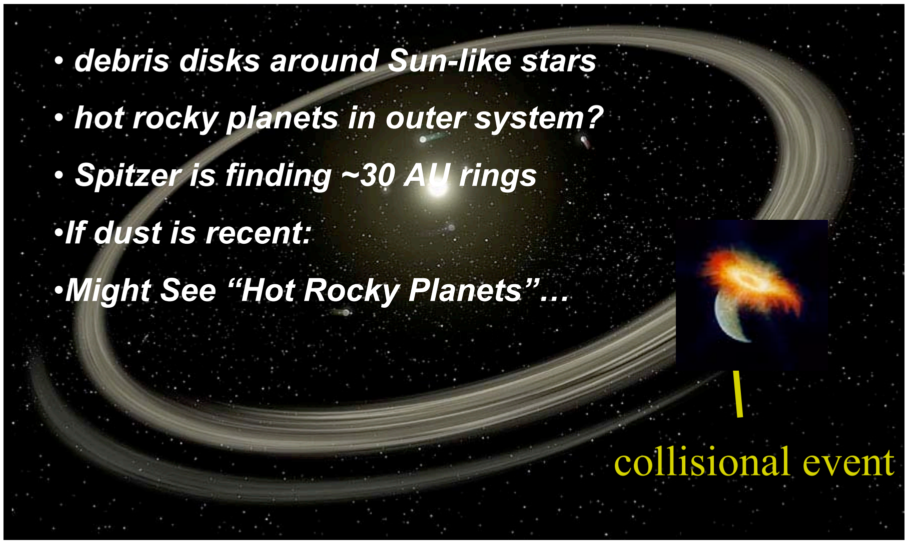
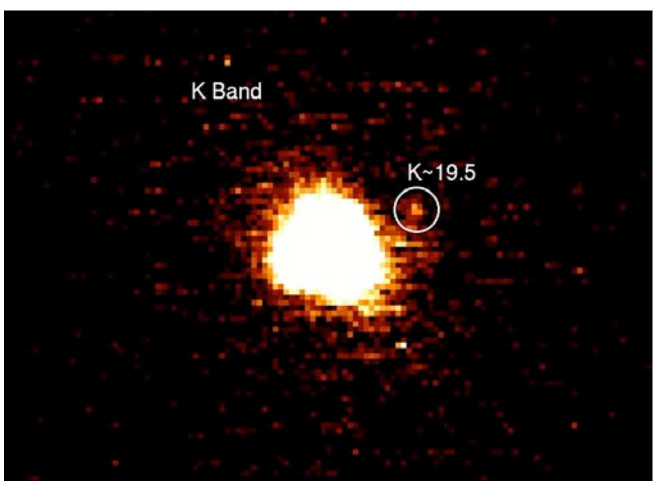
FOR EXAMPLE WHEN OUR MOON FORMED…

A Deep Magma Ocean formed on Earth for ~100 Myr?

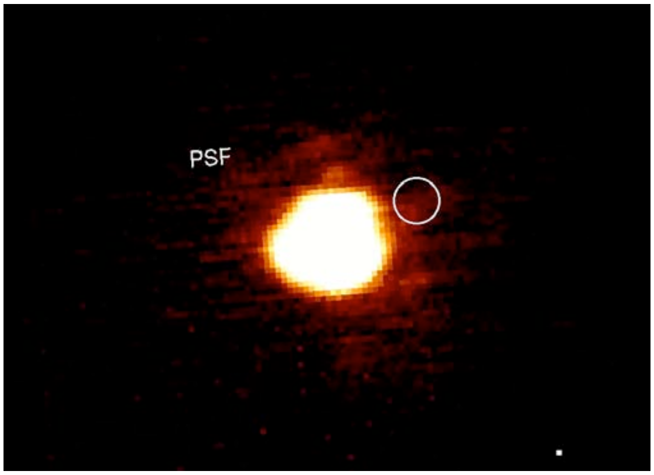
Debris Disk



An 2-4R_{Earth} object at ~2000K should have a H~20.3 at 200pc (Barman et al.) –must observe within a few Myr



Candidate is being followed up this month at Keck

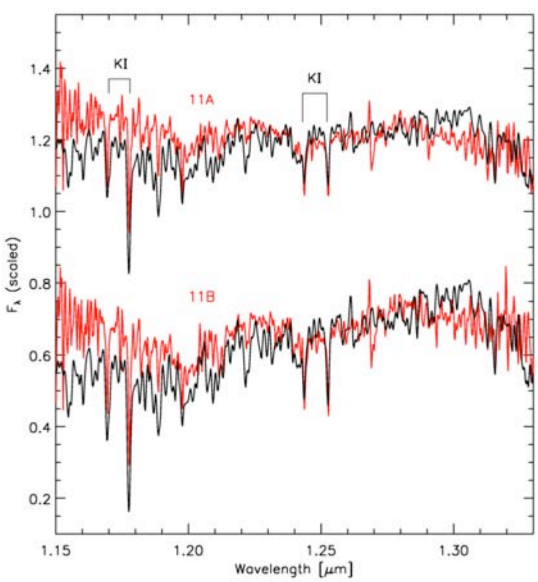


CONCLUSIONS:

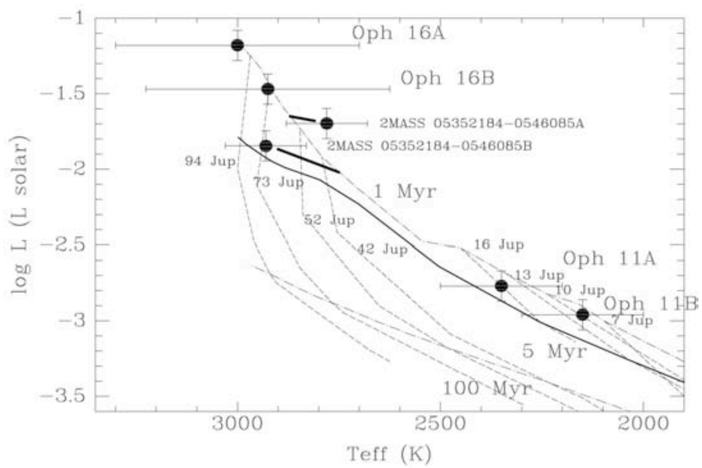
The tracks of Chabrier et al. suggest, with our spectral types, masses of 17+/-5 and 14+/-6 Jupiters for Oph 11A and B.

1. Oph 11 is one of the most extreme low-mass, wide (>243 AU) binary known. Oph 16 is the 7^{th} least bound system while Oph 11 has only V_{esc}<0.5 km/s. Such systems cannot be formed by brown dwarf "ejection" theories.
2. We deduce that ~6+/-3% of young (< 10 Myr) VLM objects are in such wide (>100 AU) systems. However, only ~0.6+/-0.1% of old field VLM objects are found in such wide systems.
3. Some young, wide, VLM binaries are evaporating, due to stellar encounters in their natal clusters, leading to a field population depleted in wide VLM systems.
4. There is the possibility to detect planetary mass companions (maybe even hot rocky ones) around young low mass brown dwarfs with LGS AO

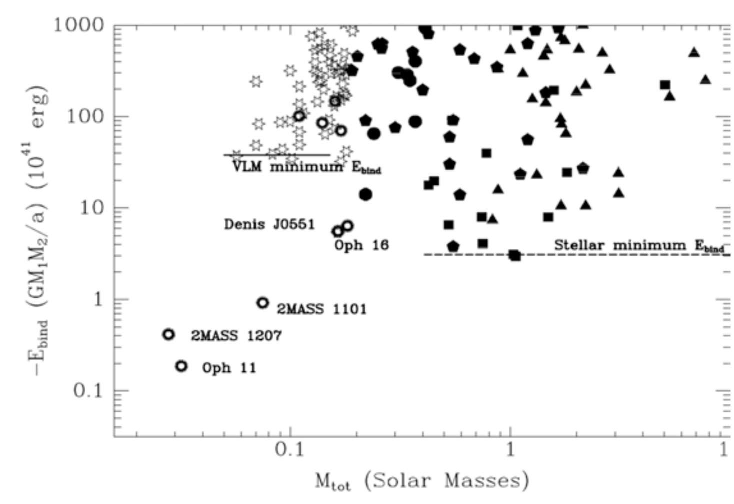
Oph 11A and Oph 11B are fit reasonably well with synthetic spectra with M9 and M9.5 types at 5 Myr ages



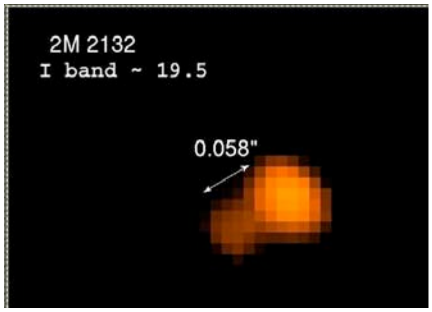
Oph 11 and Oph 16 on the HR diagram…



And Oph 11 likely has one of the lowest binding energy of any known binary (V_{esc} ~ 0.5 km/s)



June 15 2006 a NASA night of discovery at Keck with the LGS system
(Keck LGS NASA Observers Laird Close & Nick Siegler)



Discovery of a 66 mas Ultracool Binary with Laser Guide Star Adaptive Optics

•Siegler & Close et al. 2007 AJ in press

•Astroph/0702013

- Discovery of a very low mass (tight) brown dwarf binary (L6 +L8)
- *These could only be detected from the ground with the Keck LGS AO system.*